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Harnessing Radiation Use Efficiency using Spectral Reflectance Indices for climate-resilient wheat improvement in CIMMYT international nurseries

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Introduction

Wheat yields are stagnating or declining because of a plateau in genetic gains and increasing impacts of drought and heat stress due to climate change. Further yield improvements can be achieved by enhanced crop biomass through higher radiation use efficiency (RUE).

RUE, defined as the biomass accumulated per unit of absorbed radiation, is a complex trait that can be estimated by non-invasive high-throughput phenotyping (HTP) through spectral reflectance indices (SRIs).

This study aims at exploring the potential of SRIs in predicting total RUE using 50 elite genotypes (see materials and methods) grown in the field under well watered (WW), heat stress (HT) and drought (DRT) conditions.

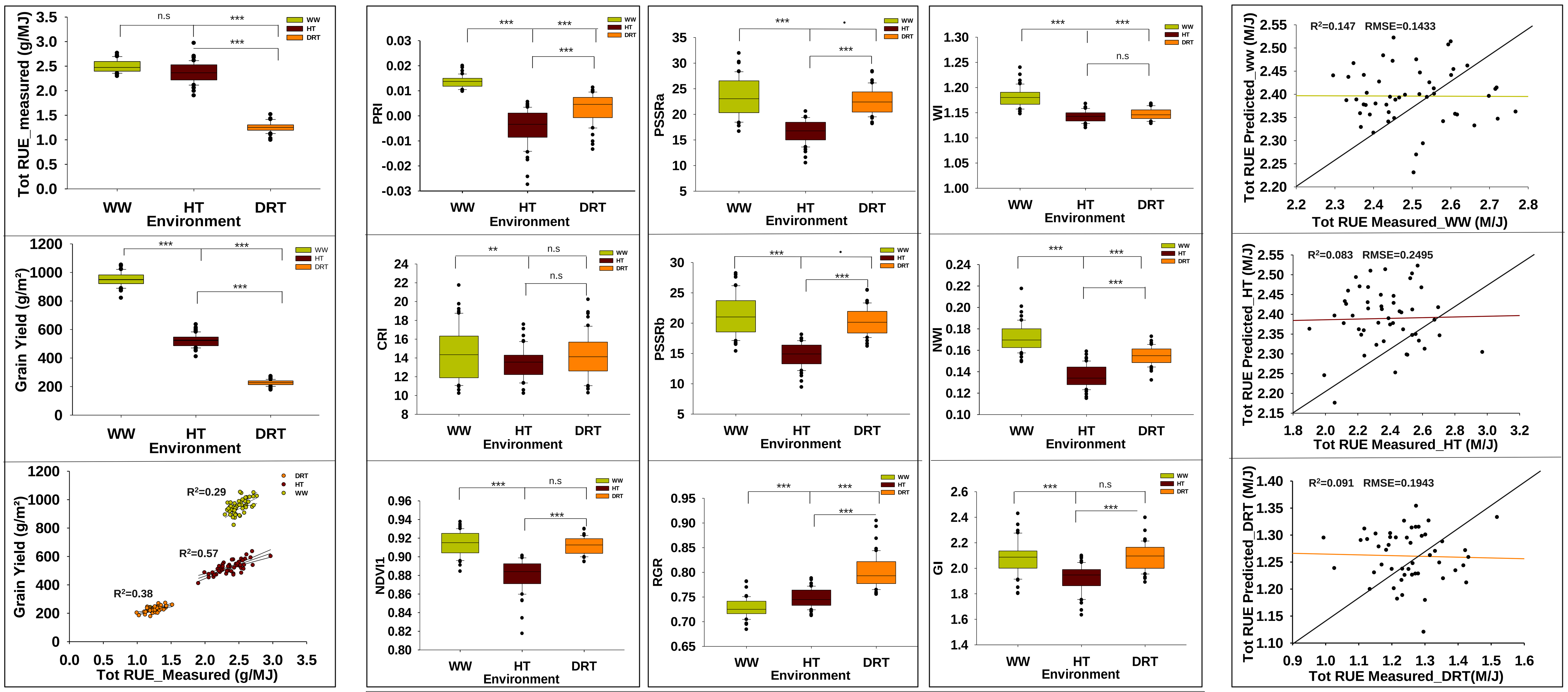
Conclusions

RUE is identified as a key determinant of GY across environments, with stronger relevance under stress.

High-throughput phenotyping and remote sensing approaches provide valuable proxies for estimating RUE, enabling rapid, non-destructive, large-scale assessment under diverse environmental conditions.

The responsiveness of SRIs to genotype × environment × growth stage interactions highlights their potentiality to reflect physiological responses. Further work with advanced modelling approaches like PLSR can enable systematic exploitation of SRIs interactions for reliable prediction of RUE across environments.

Results and Discussion



WW= Well watered; HT= Heat; DRT= Drought   n.s. = not significant; .=P<0.05; **=p<0.01; ***=p<0.001   Tot RUE= Total Radiation use efficiency

DRT showed lower total RUE than heat stress HT and WW conditions, likely due to reduced photosynthetic capacity under water deficit.

DRT had a major effect on grain yield (GY), compared to HT, likely due to the higher severity of drought resulting from steeper soil moisture depletion beyond the minimum water threshold level.

Results show that RUE is a key determinant of GY due to its strong association with photosynthesis and biomass accumulation.

The response of SRIs across environments suggests their sensitivity to the G × E interaction.

The Photochemical Reflectance Index (PRI) decreases more under HT than DRT; reflecting differential responses of the xanthophyll cycle.

Carotenoid Reflectance Index (CRI) and Normalized Difference Vegetation Index (NDVI) are reduced under stress, reflecting modulation of carotenoid content, and decreased green biomass.

Pigment-specific simple ratios for chlorophyll a and b (PSSRa and PSSRb) decrease under stress, with greater decrease under HT than DRT, reflecting stronger effect of HT stress on chlorophyll content.

The Red-Green Ratio (RGR) is highest under DRT, followed by HT and WW, reflecting more chlorophyll degradation and carotenoid-based photoprotection.

The Water Index (WI) and the Normalized Water Index (NWI) decreases under stress, with more reduced WI under DRT and reduced NWI under heat, reflecting reduction in canopy water content.

The Greeness Index (GI) indicates chlorophylls concentration, and is more effected in HT.

All indices showed strong potential to capture plant responses, but complex physiological interactions necessitate an integrative predictive approach.

The predicted RUE values derived from multiple regression model correlated weakly with the observed RUE. It is likely that collinearity has contributed to the weak regression between predicted and observed values.

More powerful multivariate techniques such as PCR and/or PLSR can overcome this problem.

Growth stage dependant variations in RUE could have also contributed to the poor correlation between predicted and observed RUE.

Materials and Methods

The experiment was conducted using 50 Elite wheat lines from each of the latest international nurseries targeted to specific environments: 32 SAWYT for drought, 45 ESWYT for irrigated-high yielding, and 23 HTWYT for heat during the 2024-2025 cropping cycle at the CIMMYT experimental station, Obregón, Mexico. All the trials were arranged in an alpha lattice design with 2 replicates. Canopy-level spectral reflectance was measured using a portable spectroradiometer (ASD Field Spec® 3), and subsample-based biomass harvest was made at the physiological maturity stage for calculation of total RUE.

WW trial: 45 ESWYT   HT trial: 23 HTWYT   DRT trial: 32 SAWYT

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